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THE

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GEOLOGIC FORMATIONS *VERSUS* LITHOLOGIC INDIVIDUALS.

A RECENT article in this JOURNAL by Bailey Willis, entitled "Individuals of Stratigraphic Classification,"[1] renews a discussion of both fundamental and practical questions coming before the geologist engaged in areal mapping, which has gone on since the earliest days of geology and seems destined to go on indefinitely. The writer recognizes that Mr. Willis voices the beliefs of many geologists, among them being Edwin C. Eckel, whose still more recent contribution to the discussion[2] indorses the statements by Mr. Willis. But there is another and fundamentally different view of the matter, also held by many working geologists, and the writer wishes to present a few remarks from that standpoint. It is desired particularly to discuss the proposition maintained by Mr. Willis that the proper cartographic units, representing "Individuals of stratigraphic classification," are "lithologic individuals," discriminated by the geologist solely on lithologic characters. Mr. Willis cites the rules of the United States Geological Survey, established some twelve years ago, concerning cartographic units, upholding them in their most literal interpretation. But the writer does not now wish to touch upon the cited rules or actual practice of the government Survey, since the question of revising those rules is, at the time of writing, under consideration by a committee appointed by the Director. There is ample room, however, for a discussion of the natural objects of a geological map and an analysis of the actual conditions facing the geologist endeavoring to express geologic facts upon a map. The writer aims to do this in no controversial spirit, making frequent reference to the articles cited simply because they are the latest expressions of a view held by many geologists.

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[1] JOUR. GEOL., Vol. IX, p. 557.

[2] "The Formation as the Basis for Geologic Mapping," JOUR. GEOL., Vol. IX, p. 708.

Before entering into the discussion of the geological problem, the writer wishes to express a protest against a tendency of the time to impoverish the language of ordinary speech by the appropriation of many of its commonest terms, having universally adopted and understood meanings, to technical and specific purposes. This is found in other languages than our own, and in the literature of other sciences than geology, but for both general and specific reasons some of the terms necessarily employed in this discussion may be mentioned as cases in point. When such terms as "group," "division," "series," "period," and "formation" are appropriated for special and limited uses the geologist is decidedly hampered in his general discussions and obliged either to employ unusual terms for common concepts, or to carefully and repeatedly explain his use of terms as he goes along. That restricted definitions of some of the terms mentioned have the sanction of the International Congress of Geologists merely makes the situation worse. The importance of this matter appears not to be limited to the indirectness of statement forced upon a writer in discussing the commonest points of geology and to the inconvenience of so doing, for unless a writer does explain his use of terms there is often uncertainty as to his meaning, and the unnatural limitation imposed may well act at times as an obstacle to clear thinking.

It seems desirable to refer to this matter because the uses of the word "formation" and of the expression "lithologic individual" or "unit" by Messrs. Willis and Eckel, in their cited articles, undoubtedly obscure the meaning of their discussions. It is true that their usages are in accordance with the cited definitions of the United States Geological Survey regarding cartographic units, and that the usage is now becoming common, so that no special criticism of their course can be intended in this reference. But as will appear, the writer's conception of the geologic formation is of something which does not receive recognition in the articles by Messrs. Willis and Eckel, while we are all nominally discussing the same thing, namely: the desirable and practicable scope of the geological map and the nature of the problem presented to the geologist in making such a map. In all frankness the writer is unable to decide to what extent the conception of the geologic formation entertained by him is actually coincident with that of the nominally restricted "formation" or "lithologic individual" in the minds of Messrs. Willis and Eckel, although it is clear that, in spite of the definitions they profess to follow, some other factors than those of the definitions are really there.

Mr. Eckel entitles his article, "The Formation as the Basis for Geologic Mapping." Under the restricted technical use of the word he soon states that he means "lithologic unit," something discriminated and defined solely on lithologic characters. But in the discussions of Mr. Eckel and Mr. Willis, and of other writers professedly dealing with a formation thus defined, there is continual evidence that to some extent other factors enter into their idea of what they designate a "lithologic unit," such as stratigraphic continuity, even if accompanied by change of lithologic character. The terms "lithologic individual" or "unit" used in defining *formation*, or given as practically synonymous with it, refer in their common or apparent meaning to a *rock*, one of the units treated by the systematic science of petrography. Mr. Willis constantly refers to the mapping of rocks. The definition of the "formation" as a "lithologic individual" lays stress on the idea that it is a result of continuity of physical conditions, securing to the sandstone or limestone mass its unity of lithologic character. But in the acknowledgment of the fact that fossils may be necessary to "identify" this *lithologic unit* is evidence of the entrance of other ideas than those of lithologic characters into the underlying conception of the *formation.* Stratigraphic position, continuity—giving it structural importance—and something of age, relatively or absolute, are clearly there but unexpressed.

The writer's conception of the geologic formation is the broad and general one, commonly entertained before the restricted use of the word "formation" was advocated—and still held, he is happy to believe, by many geologists; it is of something entirely unsystematic. The known portion of the earth consists of rock masses of various modes of origin, in which the record of earth history lies. In considering the geology of any portion of the earth, one naturally separates these rock masses into individuals or groups, large or small, for the purpose of deciphering or expressing geology. Each division possesses a certain unity varying in degree or kind according to the point of view. All but the broadest divisions may be properly called geological formations.

Each rock mass assuming importance from the geologist's standpoint stands for many things. It may be viewed from a narrow standpoint and considered to have individuality from the factors of that standpoint only. The lithologic characters may be taken into account and then it is "a lithologic individual;" its faunal contents considered, it may possibly be correct to speak of it as "a faunal unit;" but when it is spoken of as a geologic formation, there should be involved the entire geologic record it contains. Only when the student considers it in its entirety is he entitled to call himself a geologist; otherwise he is but a specialist—a paleontologist, a lithologist, a stratigrapher, or a physiographer. The writer understands the geological map to be a representation of certain geologic formations, selected to express, so far as cartographic limitations permit, the geology of the area covered.

The writer will use the term "geologic formation" in its broad sense and, in courtesy to his colleagues, consider that they must also conceive of the geological map as more than a map of lithologic individuals could be. Mr. Willis states, with justice, that we are often perplexed to know what the divisions or cartographic units of a map are intended to represent.[1] That is particularly true of formations purporting to be "lithologic individuals," which are actually heterogeneous in lithologic character and do not represent continuity in conditions of deposition. The writer believes that every definition of a geologic formation chosen as a cartographic unit should contain a statement of all the factors determining and justifying its discrimination, with due emphasis on the most important features of each case.

Mr. Willis addressed himself in the cited article to the question "Should geologists map the record of physical conditions or the record of biological conditions—rocks or fossils?" and his answer was: "Both, but with distinctions." The question might be assumed to be broad enough to cover the problem of the geological map if the term "physical conditions" could be interpreted as referring to the general physical development of the earth as recorded in rock masses. But Mr. Willis's whole discussion is directed to maintaining the idea that geology is in such an elementary state of development that our present object must be restricted to mapping "lithologic individuals, while our associates, the paleontologists, distinguish the faunal units of stratigraphy."[2] "The record of physical conditions" must then be regarded as referring only to the conditions causing the lithologic characters, by which the so-called "lithologic individuals" are to be discriminated. As already stated, the writer believes that geologists should map *geologic formations*, not rocks or fossils. A map of lithologic individuals, discriminated on the restricted grounds advocated by Mr. Willis, is not entitled to be called a geological map; it is a *lithological map*, pure and simple.

The question under discussion is really, "What should a geological map represent?" The writer's answer is that it should represent as much of the geologic development of the earth

[1] *Loc. cit.*, p. 557.

[2] *Loc. cit.*, p. 569.

recorded in the area covered as is practicable. To that end its cartographic units must be established with regard to *all* the facts and conditions of the case, and not upon the restricted basis of any part of those facts. Of course this discussion does not refer to the mechanical limitations of map-making, nor to local maps of large scale designed for some special purpose, but to the problem involved in the mapping of a geologic province on a scale similar to that of the *Atlas of the United States Geological Survey.*

This idea of the geological map is based upon the consideration that geology is the broad science of the earth, viewing it as originating in a manner still a matter of hypothesis, as developing through a long succession of changes, from that uncertain state to the present conditions. Geology deals with all the processes involved, their modes of operation, and the results. Development implies a succession of events, a series of changes, a history, and so some conception of geological chronology is inseparable from the discussion of rock masses as *geologic formations.* The available record of earth history prior to the present time is in the rock masses and their relations to each other. Geological mapping, therefore necessarily consists chiefly in representing the distribution of rock masses. The map will fulfill the purpose of expressing geologic development in proportion as the units of representation are discriminated with reference to *all the record* contained in them. If the cartographic units are determined by consideration of only a part of the information which may be used, the map will be restricted, and unnecessarily so.

It seems to the writer that the proposition to map "lithologic individuals," and to call the result even by courtesy a geological map, ignores very largely the fundamental distinction between the *rock*, as an object of certain petrographic character, and the *geologic formation*, a mass of importance in the crust of the earth, and containing far more than the record of physical conditions controlling its formation. The separation of petrography from structural geology was made nearly one hundred years ago, and to that step as much as to the recognition of paleontology is due the present science of structural and historical geology. Perhaps Mr. Willis did not intend to use the term "rock" in its natural and limited sense, yet the proposition to make a geologic map a representation of "lithologic individuals" discriminated solely on "lithologic character" affords no basis for the supposition that he had in mind the idea of the geologic formation, properly speaking. To advocate such a map is practically no advance upon the time of John Macculloch, who in 1821 published his celebrated *Geological Classification of Rocks*, etc., having stratigraphy in mind, and with no idea of the necessity for a science of rocks. There is in the idea, however, a curious combination of this old-time misconception with an element of the so-called "new geology," which is chiefly occupied with physical conditions under which the earth is sculptured and detrital rocks are formed, although this branch of geology is no more *new* than any other.

From the statements by Mr. Willis that he "by no means advocates disregard of fossils in the *identification of formations;*" that "there is a difference between using fossils as one of several means of *identification* and employing them as *essential* characters;" and that "they should not set limits in the discrimination of formations" (*italics* the present writer's), it appears that there is an unrecognized or imperfectly expressed acknowledgment that the Jenkinsville sandstone, for example, is more than a sandstone exposed in a ledge at Jenkinsville—that it is, in fact, a geologic formation. But the writer confesses that he does not fully understand the use of the terms "identify" and "essential" in these quotations. Apparently Mr. Willis would *discriminate* and *define* "formations" by their lithologic characters as the only "essential" factors, but still realizes that such formations may not be *recognizable* by their "essential" characters and that the accidental or unessential factors, fossils, may then be useful or necessary. How and where would Mr. Willis express the facts concerning certain fossils in relation to the Jenkinsville sandstone which warranted or made possible their use in *identifying* that "lithologic individual"? If any object be defined as having certain essential characters and it develops from experience that the object cannot always be identified by those characters, or, conversely, if it be found necessary to use supposedly unessential factors in its identification, there is something logically wrong in the conception of the object.

Viewing sedimentary formations as documents of geological history, the deciphering of their complete record of events requires consideration of many things. The most striking fact in many cases is the lithologic character of the formation. From this character the mass receives its petrographic designation, and from it some of the conditions of sedimentation and of local physiography at the time of deposition may be inferred. Often these factors permit further inferences as to the events preceding or following the deposition of a given stratum. But all the strictly lithologic characters have no chronologic significance. A sandstone, shale, conglomerate, or limestone may have been deposited at any time from the Algonkian to the Tertiary. As Mr. Willis clearly expresses it, "we now know that the physical characteristics of rocks are repeated from time to time, and are diverse in different provinces at the same time, and that therefore they do not afford criteria of contemporaneous deposition.[1] Much more of the record of earth development may be found in the sedimentary deposit, however, if other data are considered. Such deposits consist usually of chemical precipitates, fragments of older rocks, or of organic remains.

Lithologically the source of materials for a clastic rock may be of no consequence. A conglomerate is a conglomerate, whatever the age may have been of the rocks which were destroyed to furnish sand or pebbles. But viewing the conglomerate as a geologic formation, it is of great importance to note what earlier rock formations are represented in any given case. Even a single pebble or bowlder may throw more light upon the chronologic position of the conglomerate, and the extent and importance of the erosion which exposed the rock of that pebble, than is afforded by all other data combined. Two conglomerates in close proximity, and so situated at the locality where they are exposed that they seem to belong to the same general period of sedimentation, may possess in their pebbles evidence of events of great importance in the interval imperfectly represented by the stratigraphic line between them.

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[1] *Loc. cit.*, p. 557.

Lithologically a shell limestone is one largely composed of shells, and a coal of certain properties is bituminous coal, whatever shells or plants, respectively, may have produced the rocks in question. But viewing the coal beds and limestones, or other fossiliferous strata, as geologic formations, not "lithologic units," the significance which paleontology shows may be attached to the particular fossils found in a given case is of great importance. The record here referred to is not that of life history, but of earth history. The fossils of a "lithologic individual" may be the most significant characters it contains bearing upon its age, the extent and importance of earth development in the epoch preceding its deposition, the characters of the waters in which it was formed, and the climatic conditions of the time. From the standpoint of the investigator striving to make out the full significance of a sedimentary deposit, a constituent pebble of a recognizable older rock of known structural position is a feature possibly equal in importance to a shell, a bone, or a plant, of certain paleontologic character. Both are fossils, in a sense.

The mode of origin and the characteristic features of igneous rocks render the evidence of geologic history to be obtained from them limited as compared with that which may be derived from sedimentary formations. But it appears to the writer that much more effort should be made to read these records and to represent the information obtainable on geological maps than is commonly attempted.

The petrographic, or lithologic, character of an igneous rock serves to show its proper systematic position and leads to its designation. Such characters testify that a magma of certain chemical composition consolidated at the place where a given rock is seen, under conditions producing the mineralogical and textural result observed. What some of these conditions were can be inferred, and something of the eruptive history may be read in the petrographic characters. But these features give but little more data bearing upon geological chronology than do those of a sandstone or conglomerate. To be sure, one may be more warranted in assuming that an observed granite is of ancient formation, or that a leucite-bearing lava is of Tertiary age, than one would be in concluding that a sediment of almost any common lithologic character belonged in any particular part of the stratigraphic column. This is, however, due more to the circumstances of the exposure of an igneous mass than to any known connection between age and petrographic character.

Geologically it is of interest to know whether igneous masses are extrusive or intrusive. Although an indefinite relative age is all that is commonly determinable, there are many instances where the chronologic relation between the eruption of certain magmas and the deposition of certain sediments can be established. In a given province a certain series of eruptions may be visibly connected with a known volcanic center, while other igneous rocks of the same region are clearly independent of that center, and may be demonstrably very different from its products in age.

When any of these, or of other, geologically significant relations of igneous rock masses may be determined, and it is practicable to express them on a geological map, such representation should certainly be attempted. If such relations are ignored the map fails to satisfy the legitimate demands of the geologist for the same reason that a map of sedimentary "lithologic individuals," fails of its full usefulness.

Metamorphic rocks have been derived from all kinds of igneous and sedimentary rocks by a great variety of processes. In numerous cases the derivation of the metamorphic product is clear and it may be found in association with comparatively unaltered portions of the original mass and exhibiting transition stages. But the great majority of these interesting records of earth history belong to the oldest periods of geologic time of which we have evidence in the rocks, and the nature of the primary mass can never be established. The discrimination and representation of metamorphic rock formations should, however, be intended to express as much as practicable of this phase of earth development.

The belief that a geological map of today must be limited to the exhibition of the distribution of local "lithologic individuals or units," seems to the writer not only inconsistent with the true conception of the object of the geological map but to ignore the known facts of the stratigraphic column. It is now desired to consider a few of the practical problems presented to the areal geologist in the preparation of a geological map.

In the first place, it will be assumed that the terms "lithologic unit" or "individual" and the proviso that "they shall contain between their upper and lower limits either rock of uniform character or rock uniformly varied in character," imply that this unity in character has been derived from actual continuity or regular oscillation of conditions of sedimentation during the epoch in which the formation was deposited. If such implication is not intended, it may be remarked that a map of such units would so effectually obscure geological conditions that it could not be included within the scope of the present discussion. But the writer wishes to assert his belief, on the one hand, that many extensive sections of the stratigraphic column cannot be completely divided into mapable units of the significance above implied, and on the other hand, that the inference of continuity of conditions, suggested by lithologic character alone, must be tested by all available facts of the case to avoid falling into serious error. This belief is based upon the writer's personal experience in the stratigraphic section of the Rocky Mountain province, ranging from the Algonkian to the Tertiary, and upon his knowledge of some of the experiences of his colleagues in the United States Geological Survey work.

Where lithologic uniformity or regularity in variation of character actually stands for continuity of conditions, as far as existing facts indicate, the writer is as ready as any one to acknowledge that that fact should be recognized on the map, because it represents a fact both of geological history and of local conditions. The local importance of such a formation is surely to be recognized where it does not obscure facts of more fundamental significance. In this belief he has, for example, discriminated and mapped the *Mancos shale* of the Telluride and La Plata quadrangles in Colorado. This Upper Cretaceous formation is nearly two thousand feet in thickness, rests on the Dakota sandstone and embraces strata deposited during the Benton, Niobrara and Pierre epochs, as indicated by fossils occurring near the base and near the top of the shale complex. It is at present a matter of inference that some of the shales of this complex correspond in time of deposition to the strata assigned to the Niobrara formation, as it has been generally discriminated elsewhere in Colorado.

The Ouray limestone of Colorado, first described and named in 1900 by A. C. Spencer,[1] then the writer's assistant, was at first supposed to be wholly of Devonian age. It is nearly three hundred feet in thickness, and while not actually homogeneous is in very large part a limestone formation. Near the center a marked Devonian invertebrate fauna has been found, and above that horizon no persistent line can be drawn on lithologic character. It has been recently ascertained, however, that Lower Carboniferous fossils occur in certain places in the very uppermost layers of this local limestone unit. As study of this formation progresses it is plain that some, and possibly a considerable, thickness of Lower Carboniferous limestone was eroded from its upper portion in the time interval preceding the Upper Carboniferous. In its present partially metamorphosed condition the Ouray limestone seems in large degree a unit of continuous deposition, from the period represented by the Devonian fauna to that of the Lower Carboniferous. The writer then, for the present, accepts the local lithologic fact, and the absence of an observed explanation for the faunal change, as determining the treatment of the formation as a unit. If in the tracing out of the Ouray limestone it should be found that the inference of continuous sedimentation is incorrect and that a traceable and really sharp line, indicating a stratigraphic break, exists near the center of the apparent unit, the writer would favor an expression of that fact upon the map, if feasible. How that should be done is a matter of detail, from his standpoint. If the break in question should be found to represent a period of orogenic disturbance, with overlap of the Lower Carboniferous member, the desirability of expressing that fact wherever the limestone complex is found would be great. But for the region in which the apparent lithologic unit is now known it may be best that it should receive a single name, even if its lower and upper members be designated, respectively, as Devonian and Carboniferous.

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[1] "Devonian strata in Colorado," *Amer. Jour. Sci.* (4), Vol. IX, p. 125.

Another phase of the problem of establishing cartographic units may be illustrated by the stratigraphic section of the Rico Mountains, in southwestern Colorado, studied by a party in charge of the writer, which was cited by Mr. Willis[1] as an example of unwarranted departure from the rule requiring that lithologic character alone should be used in discriminating "formations." The section in question has a total thickness of about 4,500 feet, and lithologically presents a series of irregularly alternating conglomerates, sandstones, shales, limestones, marls, and all manner of transition beds, few of which exceed one hundred feet in thickness. There are probably fifty or sixty lithologic divisions which might be established and traced for some distance, most of which would have a fair degree of lithologic uniformity. Only by such detailed mapping can the conditions of deposition be graphically expressed. Any grouping of unlike units obscures that expression. There is no "lithologic individual" except the comparatively thin bed. The mapping of these lithologic units, however, would involve topographic maps of large scale and great accuracy, and an expenditure of time which, in view of the present condition of the survey of Colorado, renders such detailed work inadvisable. But assuming that the mapping of each "lithologic unit" were feasible and that it had been carried out, without some grouping of these units the map would be merely a lithological map. It seems improbable that even Mr. Willis would be content with such a map, in view of the range of this section. The problem of grouping the units is, however, the same as that of dividing the entire section for the purpose of representing the main ascertainable facts of geologic development.

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[1] *Loc. cit.*, p. 561.

It is known by fossil and structural evidence that the section in question embraces practically all that is present in the region of the Carboniferous (including Permian) and Triassic systems. In earlier reconnoissance surveys and reports touching the province, this general distinction has been drawn. The upper half, which has a reddish color, has been distinguished as the "Red Beds" of assumed Triassic age; the lower half, which has no prevalent reddish color, has been referred to the Carboniferous from scanty fossil evidence. In the recent areal work of the geological survey in charge of the writer, it has been found that the reddish color line is both indefinite, through gradations, and variable as to horizon. For any but crude reconnoissance work the red color line is not a practical guide. Through careful study of the section in several quadrangles, it has been found that the lower two thousand feet of the complex contains in its limestones and shales a persistent Lower Carboniferous invertebrate fauna. While extensive collections have been made from various horizons, the paleontological opinion rendered by Mr. G. H. Girty is to the effect that no faunal groups are indicated warranting a suggestion that any particular one of the many planes of lithologic change represents an interval of unrecorded events, or gives grounds for a division, for the expression of correlation with structural members of the Upper Carboniferous elsewhere known. The actual Triassic age of the upper portion of the "Red Beds" has been established by scanty but significant vertebrate, invertebrate, and plant remains, occurring within a limited vertical range. The problem, alike for the geologist, endeavoring to make an adequate geological map, and for the lithologist, required to express the grouping of the many small lithologic individuals in the structural divisions of the Carboniferous and Triassic systems, is here to find the correct line between them.

In the Rico Mountains it was found that above the complex of two thousand feet of beds characterized by the Lower Carboniferous fauna there was a series of strata about three hundred feet in thickness, generally somewhat reddish in color, sometimes markedly so, containing a fauna described by the paleontologist as distinctly different from that known in the two thousand feet of strata below and as intermediate in character between the Carboniferous and Permian faunas thus far known. The change takes place abruptly, *i. e.*, within fifteen feet. The Permo-Carboniferous fauna occurs in thin limestones through a section containing lithologic members much like strata above or below. Above this series comes an apparently unfossiliferous section of frequent and irregular changes in lithologic character. Many of the strata here are extremely like beds of the complex containing the Permo-Carboniferous fossils.

In the *Report on the Geology of the Rico Mountains* by the writer and A. C. Spencer the heterogeneous group of strata containing the Lower Carboniferous fauna was designated as the "Hermosa Formation;" that containing the Permo-Carboniferous fauna as the "Rico Formation;" and the remainder of the section was provisionally assigned to the "Dolores Formation."[1] The latter formation had already been defined as intended to include the Triassic portion of the heterogeneous "Red Beds" section of the region and apparently including the whole. The object in making the three divisions was to express geologic history, though imperfectly. The divisions were not intended to be "faunal divisions" as Mr. Willis states, but *geological divisions.* They were founded primarily on the evidence of fossils, because lithologic character utterly failed to indicate the importance of the events which must have occurred before and after the Rico epoch. The lower line of the Rico formation is accurately determinable in the field so far examined by the relations of a thin black limestone, a thin-bedded series of sandstones, fifteen feet in thickness, above it, and a reddish sandy-looking limestone. The thin black limestone is a guide because it is full of a foraminifer, *Fusulina cylindrica*, common in the Hermosa limestones and absent from the Rico beds; the other limestone because it is crowded with the Permo-Carboniferous fauna. The upper line of the Rico formation, as at present mapped, expresses the fact of the apparent limitation of the Rico fossils. The succeeding strata have been referred provisionally to the Triassic system because no known evidence gives a basis for recognizing the Permian or any other geologic unit expressive of the important events which clearly must have occurred between the Rico epoch and the deposition of the fossiliferous Triassic strata. The fact that a lithologically heterogeneous section must be scrutinized most carefully to detect planes of relative geological importance is well illustrated in this series of "Red Beds" above the Rico formation. The Rico fauna is a marine fauna; the vertebrates and invertebrates of the Triassic beds, one thousand feet above, are fresh water or land forms. No more marine sediments occur in the section of this region until the Upper Cretaceous rocks are reached. It is not now known whether strata of Permian age are present in this section or not. If that question is ever settled it will be on fossil evidence. Ultimately, the knowledge will be acquired indicating further subdivision of this section in order to express the sequence of events so imperfectly recorded in the rapidly and irregularly changing lithologic character of the strata.

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[1] WHITMAN CROSS and ARTHUR COE SPENCER, "Geology of the Rico Mountains, Colorado," *Twenty-first Ann. Rept. U. S. Geol. Surv.*, Part II, 1900.

The absolute necessity of using fossils in discriminating geologic formations is frequently illustrated in the areal mapping of Tertiary deposits in the Coastal Plain region, and even in establishing the boundary between Cretaceous and Eocene systems, although that line may represent a stratigraphic break. Thus in the Uvalde quadrangle of Texas Mr. T. Wayland Vaughan describes the uppermost Cretaceous and the adjacent Eocene formations as presenting such complex and rapidly changing lithologic characters, and as so similar in these variations that the stratigraphic line of much significance between them is not determinable except on fossil evidence. From lithologic character one would necessarily conclude that conditions of sedimentation alternated irregularly through the period represented by the section in question and no one line of change would be suggested as of special importance, or at least the one which is of greatest significance would not be indicated. There is, however, a sharp line present, indicated by the fossils of two beds in close proximity, one carrying a Cretaceous fauna, the other Eocene forms, and no single species of either the extensive Cretaceous fauna below, or of the Eocene above, has been found to cross this line. The use of this information in discriminating cartographic units is thus essential to a representation, which is entirely practicable, of important geological facts concerning this quadrangle and the Gulf province to which it belongs.[1]

Another example of the insufficiency of lithologic characters alone as means of discriminating the desirable cartographic units of a province is afforded by the southern Appalachian region. At the time when the areal work of the United States Geological Survey there was in charge of Mr. Willis, he described the conditions as regards the Paleozoic section as follows:

> Thus the Paleozoic sediments are a great complex of lenses of every grade of lithologic character, from pure limestone to conglomerate, and lithologic distinctions cease to be of value except when used as guides in small districts or when variations are traced out by continuous detailed study.[2]

Mr. Willis further explains (in the same place) that as a result of this condition it had been decided by Mr. G. K. Gilbert, his predecessor in charge of the work, to establish the cartographic units of each area mapped upon the lithologic characters there displayed. But, as a matter of fact, the section in question contained fossils, and the present excellent representation of the geologic development of the southern Appalachians, afforded by the combined atlas sheets already published, is due in large degree to the use by Mr. Willis's successors of fossils as guides in discriminating proper geologic formations where lithologic characters failed. By the use of fossils important stratigraphic horizons were recognized which had been entirely overlooked so long as local lithologic features were regarded as the only practical means of establishing cartographic units.

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[1] "Uvalde folio," *Geologic Atlas of U. S.*, No. 64.

[2] *Tenth Ann. Rept. U. S. Geol. Surv.*, p. 121.

The general chronologic scheme of geology has been established to express the evolution of the known portion of the globe. Its foundation lies in the fossils of the rocks, their demonstrated distribution and the evolution they show. At times the paleontologist, engaged in the biological side of the study of fossils, has seemed to believe that the chronologic scheme of geology was established to express the evolution of life upon the earth rather than the evolution of the earth itself. Sometimes the geologist, engrossed in the problems of the "new geology," appears to forget his own rights and to concede to the paleontologist of the narrow view mentioned the correctness of his claim. But in these later days, as the geologist and paleontologist work more and more in harmony, such limitations of view are certainly becoming rarer, and it is more generally recognized that where a common scheme of time divisions fails to adequately express the known facts of earth development and life evolution some new provision is necessary. The ideas upon this subject recently advanced by H. S. Williams[1] seem to the writer to contribute much toward the adjustment of these difficulties. But it is not desired at this time to discuss the basis of *time scales*, meaning graduated measures of time involved in either earth or life history. With Mr. Willis, the writer believes that much further investigation is necessary before complete adjustment of the time scales of geology and of paleontology can be made. In that condition lies no ground for the assumption that the geologist may not use paleontologic evidence at any time in accordance with the best knowledge of that time in deciphering the geologic record and in choosing formation units for its cartographic representation. Doctrines of catastrophism and special creation have yielded to the theory of evolution. A precise diagnostic value for a fossil in taxonomy is no longer claimed. But we still have a chronology of geology. We are now better informed than ever before as to the sequence of geologic events and as to the actual value of fossils to the geologist in all his researches.

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[1] "The Discrimination of Time-values in Geology," JOUR. GEOL., Vol. IX, p. 570.

The knowledge that life has been continuous, that faunas and floras migrate, that shore lines migrate, shows that time divisions of exact synchronous value can never be established upon either faunal changes or lithologic character of sediments alone. What the basis of the future time scale of geology will be cannot now be safely predicted. That is a matter which does not materially affect the problem under discussion.

The task of the geologist mapping a given province is to express the facts of geologic development there. He may know that his stratigraphic divisions are not to be accurately correlated with those of distant provinces. His province has its own history and his units of mapping, call them as you will, are to be discriminated primarily for the practical expression of that history. He knows that in the main the broader correlations with the history of other provinces will hold good, and he should express correlations indicated by all the evidence known.

The fact, now commonly recognized, that some faunas or floras cannot be used to establish the exact time equivalence of the beds containing them, in widely separated areas, does not seem to the writer to in the least warrant the conclusion that all correlation on fossil evidence is at present undesirable or unjustifiable.

Mr. Willis speaks of a faunal map as something desirable:

> When the map of formations [lithologic individuals discriminated without regard to fossils] is made, the way is prepared for the paleontologist to ascertain the number and bounds of the faunal units and to draw the faunal map.[1]

While the writer desires to see a discussion of the object and practicability of such a map from the paleontological standpoint, he desires, with all due diffidence, to make a few comments upon this idea.

A fauna regarded as the aggregate of associated forms living at a certain time or during a certain period of the past, embraces forms which have run their race and are disappearing, a larger number of those which may be said to be enduring, and still others appearing for the first time. Any fauna is, then, an aggregate of forms whose periods of endurance overlap in most complicated manner, not only because they appeared at different times, but because some are persistent and others comparatively ephemeral. Why should the biologist wish to map the distribution of one fauna rather than that of the many others which overlap it? If he desires to express conditions of life during various epochs, the imperfections of the fossil record, the sequence of periods or stages of development, his purpose is adequately met by a geological map.

From another standpoint, there are various contemporaneous faunas, and also a flora, the existence of the last being sometimes overlooked. There are marine, fresh water, and land faunas, vertebrate and invertebrate, living at the same time but only in part represented in any one formation. It would appear that the biological needs for maps of distribution could scarcely be represented on any one "faunal map."

It is an old simile to speak of "the book of nature." Perhaps in no line of scientific investigation is the aptness of this simile more striking than in the field of geology. The rock formations are so many historical documents of varied scope and magnitude. Some are like pamphlets, mainly devoted to a single subject; others are monographic in character, either condensed or expanded. A uniform sandstone bed, free from fossils, is a comparatively simple record; a section like the Norwegian "Silurischen Etagen 2 and 3," described by Brögger, is a monograph of many parts and chapters. The thickness of the book is no indication of its scope.

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[1] *Loc. cit.*, p. 560.

The investigation of the geology of any given area may be described, continuing this similitude, somewhat as follows: The various rock formations spread out over the area must be viewed as historical documents. Each one contains a record of its time, local or provincial, limited or comprehensive in scope and has, also, chapters relating to earlier epochs. Each has usually various parts, and it may be expressive to say that they are written in different languages. The longest chapters may not contain the most important parts of the record. Indeed, if the observer's eyes are not properly trained, he may not realize the presence of the most valuable chapters. Clearly the geologist cannot recognize the essential characters of these documents if he fails either to note the important chapters, or, noting them, is unable to decipher their meaning. For the latter case, however, he may rely on the interpretation of others, provided he gives them opportunity.

The difficulties of these historical studies are greatly increased by the imperfections, or the gaps, in the record. Some records are not in the rocks themselves, but in their relations, as seen. Some volumes are now dismembered, and parts may have been lost. Juxtaposition of leaves in the present relations does not necessarily imply that they belong to a single volume. Chapters on the same phase of history, belonging to various volumes, may be indistinguishable and lie so related that the student who is a specialist in this phase will quite surely group them incorrectly in a single volume if he ignores, or is unable to see, the other chapters, by which their proper relations are indicated. It is the geologist's duty to group the various chapters correctly in parts and volumes, with an appreciation of their broad significance.

The geological map is comparable to a locality index to this mass of records. It shows where the records may be found, and in a measure the proper chronologic arrangement, the character, and the grouping of the works. It is the whole history which the compiler of this index must have in mind. If he presents merely an index to the lithology of the region, he is doing the work of the specialist. Of one thing he may rest assured, namely, that his arrangement and his characterization of the records will be scrutinized by other students, and if his estimate of a given volume is based upon half knowledge, the other chapters will be read by more thorough investigators and the superficial or limited character of his own work pointed out

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